

## **Feedstock blending in gasifier/liquifiers, an approach to the use of biomass**

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In studies addressing national energy environmental (EE) problems we found that co-utilization of domestic solid fuels can significantly reduce national reliance on imported fuels while mitigating NO<sub>x</sub>, SO<sub>x</sub>, CO<sub>2</sub> and other undesirable emissions. Co-firing of coal and biomass for steam turbine power generation is a near term co-utilization approach that can make use of existing facilities with relatively minor modifications. However, co-gasification and co-liquification by providing fuel for more efficient combustion turbine systems including combined cycle, co-generators and fuel cells have greater EE potential. The development of optimum thermo-chemical (TC) co-conversion systems can be fostered by improving communications between the biomass and the coal sector. We here first use the large data bases from ASTM standard proximate and ultimate analysis for all fuels along the coalification curve from biomass to peat to lignite, bituminous and anthracite coal to systematize total volatiles, fixed carbon and feedstock HHVs. over the entire coalification curve with the atomic O/C ratio. To remedy a the great need for knowledge of the volatile constituents we use the much more limited data in the literature and our own pyrolysis data to develop phenomenological relations between feedstock composition and product composition and properties. This includes the constituents of the volatiles (condensable and non-condensable) and their chars and Our efforts led to a simple Dulong's HHV formula intermediate between those currently used in coal and biomass sectors that is simple to use with feedstock compositions represented by the chemical formula C<sub>n</sub>H<sub>m</sub>O<sub>p</sub>. We have also developed a plausible semi empirical model that for slow pyrolysis (seven minutes at 950 °C) gives approximate correlations of total volatile content, fixed carbon and the weight percentages of gaseous constituents with O/C of feedstock along the coalification path. The system requires the adjustment of one parameter per product species (e.g. CO, CO<sub>2</sub>, CH<sub>4</sub>, H<sub>2</sub> etc). Further we have partially extended our semi-empirical model to provide approximate analytical descriptions of the influence of other temperatures upon total gas, water, organic liquids and char yields as well as on the gaseous constituents. Finally guided by our previous studies on cellulose we attempt to include the time dimension with the goal of finding an engineering formula to connect slow to fast pyrolysis data. These relations are put forth as challenges to ourselves and to specialists in the biomass and coal sectors to provide improved engineering formulas. Such general formulas are needed to develop effective advanced co-utilization systems so that energy debtor nations can utilize all of its available domestic solid fuels to mitigate national EE problems.

### **Technical Approaches**

In an analysis of environmentally optimum systems to mitigate the 1979 oil crises we reached the conclusion that co-utilization of coal with other domestic fuels offered several national EE benefits [Green,1980, 1981]. With USA's current increased dependence upon imported fuels [EIA, 2000] these problems are now more urgent. The indirectly heated thermo-chemical co-utilization technology we have been pursuing has been impeded by the poor knowledge of pyrolysis and other basic aspects of fuel conversion. One leading USA biomass gasification expert remarked to the senior author "since we still do not know how to convert single fuels it is pre-mature to focus on conversions of fuel blends". While groups in the European Union have been pursuing co-gasification and co-liquification aggressively our group has been almost alone in addressing this USA pre-maturity problem. We have mainly done so by laboratory scale studies using indirectly heated feedstock converters to produce potentially useful gas, liquids and chars. In particular, the CCTL has fabricated about ten type laboratory scale batch systems and two continuously fed systems and have acquired considerable data with them that can assist in the solution of a broad variety of co-conversion problems. We have also carried out analytical studies that pool the large coal and biomass proximate and ultimate analysis coal and biomass data bases and the much smaller data bases on the composition of pyrolysis products. This broader look appears to reveal some systematics that should be useful in advancing co-utilization systems.

In connection with this broader look we have carried out an extensive search of the technical literature for guidance as to what must be clarified to develop a scientific-engineering basis for feedstock blending. It became obvious that knowledge as to the expected products of pyrolysis that underlies combustion, gasification, liquification or carbonization of any solid fuel is still at a very primitive level.

Despite the extensive coal literature and the rapidly developing biomass literature and many recent conferences on finding new ways of extracting energy out of coal and biomass relatively few efforts have been devoted to finding correlations between feedstock composition and pyrolysis products. It is reasonable to assume that “additivity” will be the zero’th order thermo-chemical effect in blending fuels. Thus in most situations physical or chemical synergisms or antagonisms, while important, can probably be treated as corrections. Economic synergism, however, can be of major importance since biomass, is seasonal, has limited energy density and has diverse and “recalcitrant” physical characteristics that tend to counteract its valuable environmental properties. Using biomass with more storable and concentrated carbonaceous energy sources such as coal can be useful in fostering practical co-gasification-co-liquification approaches. For efficient design of fuel blending systems it is essential to have the TC properties of the entire coal-biomass spectrum on the same basis.

In earlier publications [Green et.al 1996 a-c] We found that the hydrogen/carbon (H/C) and oxygen/carbon (O/C) atomic ratios for natural fuels are correlated by a sigmoid relationship. From proximate and ultimate analyses and HHV measurements, collected for various fuels for almost a century, large data sets of %VM, fixed carbon (FC), HHV and weight fractions [C], [H] and [O] are available over the entire coalification range. In our recent studies we assume a dry, ash, sulfur and nitrogen free (DASNF) fuel that from ultimate analysis can be assigned  $C_nH_mO_p$  basic units. We have found a simple convenient DuLong HHV formula covers the complete coalification range on both sides of peat (ironically called turf in Ireland) that is a compromise between those used in the coal and biomass sectors. While the overall data bank on proximate analysis and ultimate analysis of biomass is now very good. [Gaur and Reed 1998], the data on composition of products from 7 minute pyrolysis at 950°C is very sparse and varied. To meet the need for compositional details necessitates However, the CCTL over the years has made many pyrolysis composition measurements for pyrolysis temperatures and times in the neighborhood of ASTM’s 950 °C and 7 minutes. We have used these and other composition results available in the literature to find a correlation between gaseous compositions and the O/C values of feedstock on or near the coalification curve. We arrived at physically plausible universal correlation formula in which the yield of each  $C_nH_mO_p$  output gas correlates with the feedstock atomic availability represented by n, m and p. [Green et. al 2001a].

Green, Zanardi and Mullin [1996] have carried out a detailed phenomenological study of cellulose pyrolysis yields vs. residence time and temperatures. They used data obtained with the ultra pyrolysis system at the University of Western Ontario [UWO-Graham et. al., 1994] and with shock tube pyrolysis measurements made at Kansas State University (KSU). These data were used to establish approximate correlations between individual gaseous yields ( $CO$ ,  $CO_2$ ,  $H_2$ ,  $CH_4$ ,  $C_2H_4$ ,  $C_2H_2$ ,  $C_2H_6$  and  $C_3H_6$ ) and the total gaseous yield to give  $Y_i(t,T)$  for individual gases. The time limit,  $Y(T)$ , of these relationships has been tested with a number of feedstock data sets and provides reasonable fits with relatively few adjusted parameters [Green et al 2001].

We also consider the time (t) dimension and will report results of CCTL measurements, data in the literature and an analytical model for this variable. The overall objective is to connect fast pyrolysis yields with slow pyrolysis yields. Basically we are seeking engineering approximations applicable to all natural feedstock that can be used for fuel blending in gasifier/liquifiers. These formulas can also serve as challenges to other practitioners pursuing co-utilization systems via this high efficiency route. Common formulas can provide a means of communicating across the peat (turf) boundary between the biomass and coal sectors and also stimulate the development of more fundamental approaches to predictions for gasifier and liquifier systems.

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